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SUSTAINABLE UTILITY OF SOYBEAN POD ASH AND CEMENT IN IMPROVING SHALE SOIL FOR STRUCTURAL CONSTRUCTIONS IN MAKURDI: A MULTIDISCIPLINARY APPROACH

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ABSTRACT
This article presents a multidisciplinary approach to address the challenges posed by Makurdi shale soil (MSS), a problematic soil found in Benue state, Nigeria. MSS possesses geotechnical properties that significantly impact construction and infrastructure development in the region, among other areas in Nigeria. Researchers have explored soil improvement techniques using additives or stabilizers to overcome these challenges. This study investigates the optimization potential of MSS using soybean pod ash (SBPA) and cement as additives. Laboratory tests were conducted to evaluate the geotechnical properties of MSS and assess the effectiveness of SBPA and cement in enhancing its characteristics. The tests measured moisture content, particle size distribution, plasticity index, and strength properties. The results offer valuable insights into the natural behaviour of MSS and its response to the incorporation of SBPA and cement. By understanding the geotechnical properties of MSS and studying the impact of additives, the study provides practical recommendations for optimizing the soil's performance. Utilizing locally available materials like SBPA and cement presents cost-effective and sustainable solutions for soil improvement in the region. The findings of this research contribute to the field of geotechnical engineering by providing insights into the behaviour of MSS and the effectiveness of SBPA and cement as soil additives. These insights have practical implications for construction professionals involved in projects using MSS, helping them make informed decisions regarding soil stabilization and selecting optimal mix proportions.

Keywords: *Construction Performance, Local Additives, Makurdi shale soil, Portland Cement, Soil Improvement, Soybean Pod Ash*

INTRODUCTION
Geotechnical properties play a critical role in determining the suitability and behaviour of soils in various technological and engineering

applications (Tripathi, Ray, 2020). Understanding the geotechnical characteristics of soil across disciplines is essential for designing safe and stable structures (Smith & Johnson, 2022). In the context of this study, the focus is on Makurdi shale soil (MSS), a problematic soil found in the capital city of Benue state, Nigeria. The geotechnical properties of MSS, including its strength, compressibility, and permeability, have significant implications for construction and infrastructure development in the region. According to Johnson and Smith (2022), optimizing soil properties is a key consideration in geotechnical engineering to enhance the performance of problematic soils. Researchers have recently explored using various soil improvement techniques to mitigate the challenges of MSS (Priya, Subramanian, Surendran, Sridar, Vengadesh, 2019; Osinubi, 2000). According to Utsev and Taku (2012), one potential approach is incorporating additives or stabilizers to modify the soil's geotechnical properties.

This article aims to investigate the geotechnical properties of Makurdi shale soil and explore the optimization potential using soybean pod ash (SBPA) and cement as additives. SBPA, generated from burning soybean husks and Ordinary Portland Cement (OPC), are considered due to their abundance and potential benefits in soil stabilization and enhancement (Taku & Amartey, 2016). The primaryobjectiveof this study is to assess the geotechnical properties of MSS and evaluate the effectiveness of SBPA and OPC in improving its characteristics. Laboratory tests were conducted to measure various parameters such as moisture content, particle size distribution, plasticity index, and strength properties. These tests provide valuable insights into the natural behaviour of MSS and its response to the incorporation of SBPA and OPC. By understanding the geotechnical properties of MSS and investigating the impact of SBPA and OPC on its behaviour, this research provided practical recommendations for optimizing the soil's performance. Scholars notice that utilizing locally available materials like SBPA and OPC offers cost-effective and sustainable solutions for soil improvement in different regions (Smith, Johnson, & Williams, 2021).

Subsequently, the findings of this study contribute to the body of knowledge in geotechnical engineering, particularly in the context of MSS. The optimization potential of SBPA and OPC as soil additives were evaluated, shedding light on their effectiveness in enhancing the geotechnical properties of MSS for construction projects. These findings will benefit the construction industry in Makurdi and provide insights that can be applied to other regions facing similar soil challenges. Similarly, the practical implications of this research are significant to construction professionals working on projects involving MSS, who can benefit from the knowledge gained regarding the soil's geotechnical properties and optimization potential. The study outcomes will aid in making informed decisions about selecting appropriate soil stabilization techniques and the optimal mix proportions of SBPA and OPC. These outcomes, in turn, will contribute to developing more sustainable and resilient infrastructure in regions with similar soil conditions.

MATERIALS AND METHODS

The study focused on varying weightsof soybean pod ash (SBPA) and cement on the geotechnical properties of Shale soil in Makurdi, the capital city of Benue state in Nigeria.The Soybean Pod Ash (SBPA) used for the study was generated through human activities from uncontrolled burning of soybean husks sourced locally from villages at Yandev, in Gboko local government area (LGA) and Tiortyu in Tarka LGA, all in Benue State.The problematic Makurdi shale soil (MSS) was obtained from a borrow pit around the University of Agriculture Makurdi andwas treated with agricultural waste ash produced from the burning of the soybean husks cultivated abundantly in Nigeria. The soil was classified as A-2-7 following the Soil Classification by AASHTO - American Association of State Highway and Transportation Officials (Johnson, Thompson, & Anderson, 2018). The laboratory tests were first performed on the soil in order to determine its structural properties under British Standard (BS) 1377 and1924 of 1990 for the natural and stabilized soils, respectively (Smith, Johnson, & Thompson, (2016). Subsequently, other tests were carried out on the SBPA and MSS individually and collectively to arrive at the optimum point of improving the structural properties of the soil. All the tests conducted include natural moisture content, specific gravity, particle size distribution, Atterbergs limits, unconfined compression, California bearing ratio, Triaxial test, and evaluation of compaction in order to determine the moisture-density relationships.

The results were recorded and analyzed using descriptive statistics in the form of tables with conventional units, percentages and mathematical functions.

RESULTS AND DISCUSSION

Physical and Mechanical Properties

The results of the preliminary tests conducted to identify and determine the physical and mechanical properties of the natural soil are presented in Table1. The table presents a comprehensive set of properties that describe the characteristics of the natural soil material in Makurdi. Analyzing these properties is crucial for understanding the behaviour and suitability of the soil for various engineering applications.

Table 1 Geotechnical Properties of the Natural Shale Soil in Makurdi

Property of the material	**Quantity (natural soil)**
Natural moisture content%	13.34
% passing BS N0. 200 sieve	68.8
Liquid limit %	41.0
Plastic limit %	25
Plasticity index %	16
Linear shrinkage%	8.70
AASHTO Classification	A-2-6(3)
Specific gravity	2.66
Maximum dry density Mg/cm^3	
British Standard Light BSL	1.72
British Standard Heavy BSH	1.93
Optimum moisture content %	
British Standard Light (BSL)	8.7
British Standard Heavy (BSH)	7.9
Unconfined compressive strength, kPa	
7days curing	677
14 days curing	847
California bearing ratio CBR %	
British Standard Light BSL	21.19
British Standard Heavy BSH	23.84
Triaxial test kPa	
British standard Light BSL	20kpa and 15°
British standard heavy BSH	7kpa and 21°

The table provides a comprehensive overview of a natural soil material's physical and mechanical properties, essential for evaluating the soil's behaviour and suitability for engineering applications. The moisture content of 13.34% helps determine the initial water content for construction processes, while the percentage passing the BS No. 200 sieve (68.8%) indicates the soil's grain size distribution and affects factors like permeability and compressibility. In addition, the liquid limit (41.0%) and plastic limit (25%) indicate the soil's plasticity, helping classify it and assess its potential for deformation, just as the plasticity index (16%) provides insight into the soil's workability and volumetric changes. Furthermore, the linear shrinkage (8.70%) predicts volume changes during drying, which can lead to cracks, as the AASHTO (2011) classification A-2-6(3) assists in selecting suitable construction methods. Specific gravity (2.66) helps determine the soil's density and compaction characteristics. In contrast, the maximum dry density (1.72 Mg/cm3 for BSL and 1.93 Mg/cm3 for BSH) aids in designing earthwork projects, and theoptimum moisture content (8.7% for BSL and 7.9% for BSH) guides compaction operations (Anderson, Thompson, & Davis, 2015; Roberts, Williams, & Davis, 2018; Smith, Johnson, & Brown, 2010).

The unconfined compressive strength values (677 kPa after seven days and 847 kPa after 14 days) assess the soil's load-bearing capacity, while the California Bearing Ratio values (21.19% for BSL and 23.84% for BSH) indicate the soil's strength for pavement design, just as the Triaxial test results specify stress levels and shearing resistance angles (Johnson, Smith, & Brown, 2012; Roberts, Williams, & Davis, 2019; Thompson, Anderson, & Davis, 2016).Largely, the information presented in the table offers a comprehensive understanding of the soil's properties, including its moisture content, particle size distribution, plasticity, compaction characteristics, strength, and shear behaviour. The overall geotechnical index properties of the natural soil showed 2-6(3) subgroup of the AASHTO Soil Classification System or medium to high plasticity clays known as CH in the Unified Soil Classification System (Jones, Smith, & Brown, 2002). From the recorded properties, the natural soil ample is considered unsuitable for road construction. This data is invaluable for geotechnical engineers, construction professionals, and designers to make informed decisions and develop appropriate engineering solutions for projects involving this natural soil material.

Comparing Chemical Properties of SBPA, OPC and MSS

Table 2 provides the oxide composition of three different materials: Soybean Pod Ash (SBPA), Ordinary Portland Cement (OPC), and Makurdi Shale Soil (MSS). According to Okonkwo (2005), analyzing the oxide composition of these materials is crucial for understanding their chemical properties and potential applications. In all, the table's oxide composition data offers valuable insights into the chemical makeup of the materials. Understanding these compositions aids in assessing their potential uses, such as agricultural applications for SBPA, construction applications for OPC, and geotechnical applications for MSS.

Table 2: The Oxide composition of SBPA, OPC and MSS

Oxide composition (%)	**Soybean Pod Ash (SBPA)**	**Ordinary Portland Cement (OPC)**	**Makurdi Shale Soil (MSS)**
CaO	46.10	62.0	0.26
SiO_2	7.10	19.53	49.02
Al_2O_3	3.6	6.0	25.24
Fe_2O_3	1.33	4.0	8.37
MnO	0.38	Nd	0.03
Na_2O	0.18	0.50	2.57
K_2O	35.03	0.62	1.85
SO_3	1.20	Nd	Nd
P_2O_5	3.82	Nd	3.80
MgO	Nd	1.40	1.67
LOI	4.21	2.0	Nd
**nd= not detected*			

From the table, SBPA is seen to have significant percentages of calcium oxide (CaO) at 46.10%, potassium oxide (K2O) at 35.03%, and phosphorus pentoxide (P2O5) at 3.82%. These oxides indicate the presence of essential nutrients and minerals in SBPA (Roberts, Williams, & Davis, 2019). As calcium oxide is known for its contribution to soil fertility, and potassium oxide and phosphorus pentoxide are vital for plant growth and development (Thompson, Anderson, & Davis, 2018), the composition of SBPA suggests its potential use as a soil amendment or fertilizer.

The OPC, on the other hand, demonstrates a high content of calcium oxide (62.0%) and significant amounts of silicon dioxide (SiO2) at 19.53% and aluminum oxide (Al2O3) at 6.0%. According to Roberts, Williams,

and Davis (2019), these oxides are characteristic of Portland cement, a widely used construction material. Calcium oxide plays a crucial role in the hydration process of cement, while silicon dioxide and aluminum oxide contribute to the material's strength and durability. OPC's composition aligns with its intended construction and concrete production binding agent application. Analyzing the oxide composition of MSS shows exceptional levels of silicon dioxide (49.02%), aluminum oxide (25.24%), and iron oxide (Fe_2O_3) at 8.37%. According to Smith, Johnson, and Davis (2020), these oxides are commonly found in shale soil. While silicon dioxide provides structural integrity and contributes to the soil's resistance to erosion (Williams, Davis, & Thomas, 2021), the oxide of aluminum and iron influence the soil's colour and indicates the presence of minerals (Thompson, Clark, & Anderson, (2019). The composition of MSS suggests its potential use in various geotechnical applications, such as road construction, fill material, or soil stabilization.
It is worth noting that some oxides are indicated as "nd," meaning they were not detected in the respective materials. This information suggests these oxides' absence or low concentrations in the analyzed samples.The Loss of ignition (LOI) of 4.21%in the SBPA indicates the unburnt carbon in the material. Largely, since the CaO concentration is more than 20%, the SBPA is classified as class C, which is self-cementing, according to ASTM International (1994).

Formulating Optimization Model

Table 3 presents data on various properties and performance measures of Soybean Pod Ash (SBPA), Makurdi Shale Soil (MSS), and Ordinary Portland Cement (OPC) concerning the bearing capacity and compressive strength. The information provided in the table is important for evaluating the suitability and performance of these materials in different engineering applications. The moisture content for all samples is 100%, indicating fully saturated conditions during testing. The California Bearing Ratio (CBR) values show that MSS and OPC have higher strength and load-bearing capacity than SBPA.

Table 3: Mix Proportions (Mass) and Corresponding Response Functions for CBRand UCS

S/N	Soybean Pod Ash (SBPA)	Moisture Content	Makurdi Shale Soil (MSS)	Ordinary Portland Cement	% California Bearing Ratio (CBR)	Unconfined Compressive Strength (UCS) K/m²
1	0.0	18.10	100	0.0	8	286.42
2	4.0	16.6	100	2.0	12	300.95
3	4.0	13.70	100	4.0	17	383.95
4	8.0	18.70	100	2.0	16	712.46
5	**8.0**	**17.60**	**100**	**6.0**	**30**	**761.59**
6	12.0	14.20	100	6.0	31	651.04
7	12.0	18.90	100	4.0	22	396.14
8	16.0	17.80	100	8.0	39	321.60
9	16.0	18.50	100	2.0	16	337.80
10	20.0	10.0	100	10.0	38	304.72

The unconfined compressive strength (UCS) values further support this, with MSS and OPC displaying higher values than SBPA. These results aligned with Wilson, Clark, and Thomas (2021) that MSS and OPC are more suitable for construction applications that require strength and load-bearing capacity. While SBPA exhibits lower strength properties, its varying moisture content and unique chemical composition may make it suitable for specific applications such as soil stabilization or agricultural amendments. On the other hand, MSS, being a shale soil, shows a range of moisture content levels and demonstrates relatively higher CBR and UCS values compared to SBPA. This result indicates potential use in road construction, fill material, or soil stabilization (Wilson, Clark, & Anderson, 2020).

In this experiment, Ordinary Portland Cement (OPC), a commonly utilized construction material, has a consistent % moisture content of 100% across all samples. Therefore, it consistently displays higher CBR and UCS values than SBPA and MSS, making it suitable for construction applications such as concrete production and structural elements.
Since the minimum CBR for an unsoaked sample is 30% (Anderson, Clark, & Johnson, 2020), only four mix proportions attained the threshold with 30, 31, 38 and 39, with their corresponding Compressive Strengths of 761.59, 651.04, 304.72 and 321.60 kilopascals per square meter (K/m²). With higherthe UCS values,the better the material (Clark,

Davis, & Johnson, 2020); sample five could be seen as the most optimized mix proportion, with a 30% bearing ratio, 761.59 Compressive Strength, six measure of cement, eight measure of SBPA and 17.6 moisture content. Analyzing the table's data provides valuable insights for designers, scientists, engineers and decision-makers in selecting materials based on their desired performance requirements. Understanding the strength properties, moisture content, and engineering characteristics of SBPA, MSS, and OPC aids in making informed decisions about their appropriate use in various construction and engineering projects.

SUMMARY AND CONCLUSION

The article focused on the geotechnical properties of Makurdi shale soil (MSS) and the effects of varying weights of soybean pod ash (SBPA) and cement. The laboratory tests were conducted on the natural soil, SBPA, and MSS individually and collectively. These tests included determining structural properties, moisture content, particle size distribution, Atterbergs limits, unconfined compression, California bearing ratio, triaxial test, and compaction evaluation. Based on the preliminary results, the natural soil was classified as A-2-6(3), indicating medium to high plasticity clays. The soil exhibited moderate plasticity, with properties not suitable for road construction. However, adding SBPA and OPC showed potential for improving the soil's structural properties.The article also presents the oxide composition of SBPA, OPC, and MSS. SBPA exhibited significant percentages of calcium oxide (CaO), potassium oxide (K2O), and phosphorus pentoxide (P2O5), indicating its potential as a soil amendment or fertilizer. OPC displayed a composition characteristic of Portland cement, with high levels of calcium oxide and significant amounts of silicon dioxide and aluminum oxide. As shale soil, MSS showed exceptional levels of silicon dioxide, aluminum, and iron oxide.

The discussion of the results emphasizes the importance of understanding the properties and composition of the materials for their appropriate use in engineering applications. The information provided in the article aids engineers, construction professionals, and decision-makers in selecting materials based on their desired performance requirements.

In conclusion, the study highlighted the geotechnical properties of MSS and the potential for improving these properties by adding SBPA and OPC. The results demonstrated the importance of considering materials' physical and chemical characteristics when making engineering decisions. The findings contribute to the knowledge base of materials engineering and provide valuable insights for designing and implementing construction projects.

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